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High-precision dating and ancient DNA profiling of moa (Aves: Dinornithiformes) eggshell documents a complex feature at Wairau Bar and refines the chronology of New Zealand settlement by Polynesians

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A B S T R A C T

Wairau Bar, New Zealand, is one of the few prehistoric sites in the world that could lay claim to being a site of first human intrusion into a pristine environment. It is certainly one of the best places to study human impact on a hitherto unoccupied land. Its potential status as a colonization phase settlement for New Zealand's Maori population raises questions that require fine-grained chronological resolution. Unfortunately, the simple stratigraphy of the Wairau Bar site has offered little opportunity for the development of high-resolution chronologies. This situation changed recently when new excavations exposed a complex, midden-rich feature which contained a wide range of dateable material, including hundreds of fragments of eggshell of the extinct megaherbivorous moa (Aves: Dinornithiformes). The thick eggshell, with its minimal inbuilt age and high resistance to contamination, is an ideal material for radiocarbon dating. Its refractory properties also allow high-quality preservation of DNA. The moa eggshell yielded radiocarbon that facilitated reconstruction of the chronology of deposition at a fine resolution. Ancient DNA profiling of eggshell fragments was used to ensure that dated fragments were from different individuals. Bayesian analysis of the dated fragments showed that the midden was laid down over a brief period in the early decades of the 14th century CE. This improved chronology provides a benchmark for understanding the duration of site occupation and revises current interpretations of the timing of Polynesian settlement of New Zealand.

1. Introduction

Wairau Bar is one of the earliest and most significant archaeological sites in New Zealand. It has the widest range and largest number of artefacts typical of the Archaic Phase of East Polynesian culture of any site in the Pacific (Higham et al., 1999) and is the source of much of our knowledge about the earliest settlement phase in New Zealand and of the historical connections between New Zealand and the tropical East Polynesian homelands (Duff, 1956; GOLSON, 1959; Davidson, 1984). Following the discovery of two "moa-hunter" burials in 1939 and 1942 by J.R. Eyles, the site was investigated over several field seasons between 1942 and 1964 by teams from the Canterbury Museum as well as by Eyles and others (Brooks et al., 2011). Most of this work focused on the many burials discovered at the site and their associated grave goods although, later, the stratigraphy and other aspects of the site were also investigated (Trotter, 1977). This work was conducted either before the invention of radiocarbon dating or during its infancy.

The importance of understanding the chronology of the site has long been recognized (Duff, 1956, Trotter, 1977, Anderson, 1989, 1991, Challis, 1991, Higham et al., 1999); indeed, the first radiocarbon determinations from a New Zealand archaeological site

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were on samples from Wairau Bar (Duff, 1956: xii). However, access to the site was restricted from the mid-1960s at the very time when radiocarbon dating was becoming a routine tool for archaeologists. As a result, modern attempts at dating the site have been reliant on the use of curated material from the early excavations which was of questionable provenance. In fact, the additional problems of potential inbuilt age (unidentified charcoal samples) and the applicability and efficacy of methods of pretreatment (bone samples) mean that nearly all of the dates produced prior to 1999 are considered unreliable (Higham et al., 1999). To further complicate matters, a major fluctuation in the southern hemisphere terrestrial radiocarbon calibration curve is centred on the 14th century CE, making it difficult to obtain high-resolution chronologies for the Polynesian colonization phase (McFadgen et al., 1994). Finally, the site itself presents a particular problem for resolving chronology in its shallow, unbroken stratigraphy. The site is essentially one layer so it is difficult to improve the precision of dates using statistical tools which rely on knowledge of stratigraphic position to constrain date ranges.

In 1999, Higham et al. (1999) set out to refine the site chronology by dating moa eggshell (using pieces from 11 more-or-less complete but broken eggs) from ten of the burials, as well as marine shell samples ($n = 2$) from two midden contexts. The resulting dates, calibrated using the Intcal98 (Northern Hemisphere) calibration curve (Stuiver et al., 1998), indicated that the site had been occupied from the late 13th century. These dates are now considered the most reliable suite for dating the burial complex at Wairau Bar, but because they were from a number of different features of unknown stratigraphic relationship they cannot be combined to provide a high precision date of a single event.

Recent developments have provided the opportunity to generate a high precision age estimate for a single feature at Wairau Bar. First, a new program of excavations in 2009 produced multiple samples of moa eggshell from a single feature. Moa eggshell has negligible inbuilt age and is resistant to contamination (Higham, 1994). Deriving from a single feature Bayesian methods could be used to improve the dating precision. Underpinning this work, ancient DNA (aDNA) analysis was used to eliminate the possibility of dating multiple fragments derived from the same egg.

2. Excavations in 2009

Excavations at Wairau Bar in January 2009 were carried out under the direction of RW and CJ (Brooks et al., 2009). They were carried out as part of a program of repatriation of human remains that had been excavated in the mid twentieth century. Several parts of the site were investigated, including middens, living floors, and food preparation areas. One of the food preparation areas contained a circular array of five very large cooking pits which were individually up to 6 m in diameter. Stratigraphic interpretation of a fully excavated portion of one of these, Oven Pit 1 (Fig. 1), showed that the feature contained a midden deposit that was likely accumulated over a very brief span of time. The radiocarbon samples were derived from this pit feature.

2.1. Oven Pit 1

Oven Pit 1 was 6 m in diameter by 1.2 m deep, and contained a range of faunal material, charcoal, and fire-cracked rocks, excavated into a sterile, pebbly silt subsoil. About a third of the feature was excavated stratigraphically according to natural layers and, within layers, in 100 mm spits by quadrant (NE, NW, SE, SW).

The oven feature had a relatively simple stratigraphy of three layers:

Layer 1 (0–200 mm) – Plough zone, a mixture of topsoil and fragmented midden.

Layer 2 (200–1200 mm) – Pit fill, a mix of shell and bone midden in an ashy soil matrix. The lower 500 mm or so was dominated by ashy soil, gravel and fire-cracked rocks, with fewer faunal remains.

Layer 3 (1200 mm to base of excavation) – Sterile grey, silty, subsoil overlying a layer of large oven stones.

All material was sieved (3.2 mm screen size) on site and the residue in the sieves was returned to the Otago Archaeology Laboratories (University of Otago) for analysis. The material in this study was from a 1 × 1 m column sample, "Column Sample A" (Area 4, Unit J), selected for detailed faunal analysis. The fauna from Oven Pit 1 included the extinct moa (bone and eggshell) and at least 20 species of other birds, including the extinct eagle *Hieraaetus moorei*, as well as marine mammals (pinnipeds), dog (*Canis familiaris*), fish, and shellfish (cf Scofield et al., 2003). The moa eggshell, 1135 fragments (356 g), was of particular interest for this study because of its ideal qualities for radiocarbon dating.

The construction, use and infilling of the oven feature can be described in terms of a four-phase event sequence. 1) the construction of the oven, 2) its use for cooking, 3) the generation of the midden, 4) the infilling of the oven feature with the midden deposit 5) incorporation of the area within the general living zone of the community (deposition of artefacts). It is likely that events 1–4 happened as a single activity given the absence of sterile layers within the fill. Further evidence that the midden deposit represents a single event is the fact that the faunal content of each spit is the same, and that at least one individual moa egg was represented by fragments found in spits 1, 2 and 4 (see below). Although we cannot demonstrate that the midden represents food that was cooked in the oven, there is no doubt that there is very little time depth involved in the generation of the midden (event 3) within the context of a site that was only occupied for a matter of decades (Higham et al., 1999: 425).

3. Research aims and methods

This work was aimed at refining the chronology of the Wairau Bar site by generating the first high precision age estimate from a single, short-duration feature.

We adopted a three-stage methodology as follows:

3.1. Sample selection

The selected substrate for dating, moa eggshell, has already been shown to have ideal dating properties (Higham, 1994). However, it has one big drawback and that is that all the fragments available for dating could be from the same egg. To avoid this situation we used aDNA methods (Oskam et al., 2011) to isolate a sample for dating that comprised material from different eggs.

From the total sample of 1135 eggshell fragments a least one fragment was selected from each quadrant of each spit that contained eggshell ($n = 36$ fragments). Each fragment was divided into two sub-samples – one for aDNA analysis and one for AMS ^{14}C dating. Using methods described in Oskam et al. (2010, 2012) each of the aDNA sub-samples was genetically profiled to parent species and haplotype. Analysis of nuclear microsatellite was carried out using markers developed specifically for moa by MA (Allentoft et al., 2009, 2011) and applied to the eggshell (Oskam et al., 2012). This allowed further potential differentiation of the source of each piece on the basis of preserved and highly polymorphic nuclear DNA.

3.2. AMS Dating

Samples generated in stage one of the program were submitted to the radiocarbon dating laboratory of the Institute for Geological and Nuclear Sciences, Wellington, for AMS dating. The AMS dates were obtained on samples prepared by cleaning all exterior surfaces to reduce contamination, first mechanically (by grinding using a Dremel® bur), and then chemically by acid etching (0.5 M HCl for 2 min).

3.3. Bayesian analysis

The "single-phase" nature of the distribution of the dated materials within the midden deposit meant that Bayesian methods could be applied to constrain the age range (Nicholls and Jones, 2001) . Bayesian analysis under the assumption that the samples represented independent estimates of onset, end, and duration of a single phase was carried out using DateLab® V3.5 (Jones and Nicholls, 2002). OxCal (4.1) produced identical probabilities but the DateLab® software produces additional detail on the HPDs.

4. Results

The results of sample selection and dating are described below.

4.1. Sample selection

The DNA analysis identified the 36 samples to 3 moa species; *Dinornis robustus (D. robustus)* $n = 4$, *Emeus crassus* (*E. crassus*) $n = 13$, *Eurapteryx curtus* (*E. curtus*) $n = 19$. Of these, the mtDNA haplotypes were established (*D. robustus* $n = 2$; *E. crassus* $n = 3$; *E. curtus* $n = 3$) (Table 1) from all 36 pieces, indicating a minimum of 8 individual eggs that were distinguishable from one another on the basis of species and mitochondrial haplotype (Oskam et al., 2011).

Microsatellites were used to identify specific individuals within haplotype. Five microsatellite loci (MS2, Allentoft et al., 2009; MA21, MA38, MA44, MA46, Allentoft et al., 2011) were used for this analysis, although not all fragments yielded a full 5-locus profile. As discussed in Oskam et al. (2012), the reduced nuclear DNA preservation within eggshells resulted in a high proportion of allelic dropout. The principal use for the genotyping in that study was to discriminate between individual eggshell fragments only; this current study had that objective but also used the genetic profiles to determine if eggshell fragments could, on the basis of genotype, be reasonably assigned to a single egg.

The results of the DNA analysis were used to group the samples into one of three categories (Table 1) as follows.

Category A. Suitable dating samples. Each fragment was genetically distinct from all other fragments, based on the mtDNA haplotype, the microsatellite profile or on both features. To fall into this category, eggshell fragments must not have any shared alleles or, if they do have shared alleles then they must also have at least one contradictory allele.

Category B. Fragments of the same eggs. Groups of fragments that were genetically identical in both the mtDNA haplotype and microsatellite profile. To fall into this category, eggshell fragments

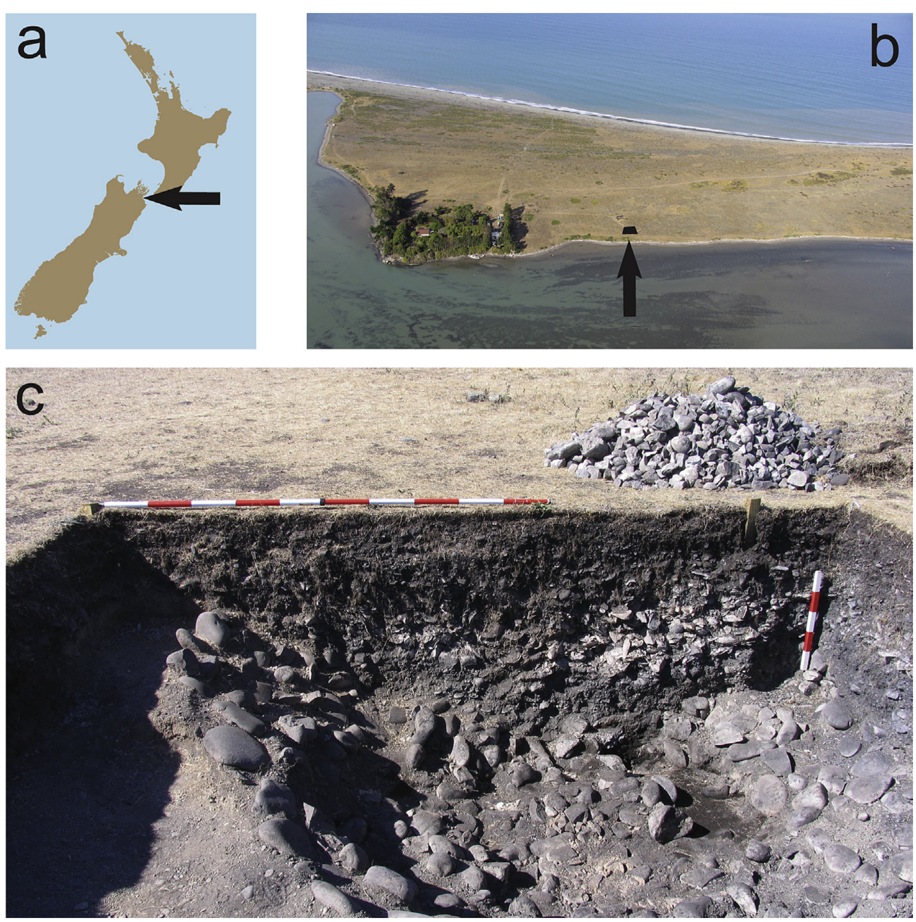

Fig. 1. Site location. a. New Zealand showing location of Wairau Bar; b. Wairau Bar showing location of oven pit (Oven Pit 1); c. Oven Pit 1 (horizontal scale – 2 m, vertical scale 0.5 m).

Table 1
Details of samples used in Categories A and B. Category A samples submitted for dating are underlined. Category C samples were discarded from subsequent analysis and are not shown.

Category	Sample no.	Species & haplotype	Microsatellite									
			MS2		MA21		MA38		MA44		MA46	
			Allele	Allele 2	Allele	Allele 2	Allele	Allele 2	Allele	Allele 2	Allele	Allele 2
A	CJ20	EMCR1	–	–	124	132	92	104	81	81	60	60
	CJ21	EUCU2	124	130	116	144	94	102	79	83	60	69
	CJ22	EUCU3	122	126	–	–	–	–	79	79	60	66
	CJ23	EMCR3	–	–	–	–	–	–	81	81	60	66
	CJ28	EUCU3	122	126	118	130	–	–	79	83	60	66
	CJ30	EUCU3	122	126	–	–	94	96	79	79	60	66
	CJ31	EUCU2	124	130	–	–	–	–	79	83	60	63
	CJ34	EUCU3	122	124	–	–	–	–	–	–	–	–
	CJ39	EUCU2	124	130	–	–	94	102	79	83	60	69
	CJ42	EMCR1	108	112	–	–	96	110	–	–	–	–
	CJ49	EUCU1	120	130	–	–	–	–	–	–	–	–
	CJ50	EUCU2	110	124	122	132	–	–	79	83	66	66
	CJ51	EUCU2	110	118	130	132	98	–	79	83	60	–
	CJ57	EMCR1	108	108	118	130	96	104	79	81	–	–
	CJ58	DIRO1	–	–	–	–	–	–	–	–	–	–
	CJ60	EMCR1	108	108	–	–	–	–	81	85	–	–
B	CJ15	EUCU2.1	124	130	116	144	94	102	79	83	60	69
	CJ21	EUCU2.1	124	130	116	144	94	102	79	83	60	69
	CJ39	EUCU2.1	124	130	–	–	94	102	79	83	60	69

must have at least four shared alleles and must have no contradictory alleles. These samples could be used to argue for contemporaneity of the deposit, if samples were found in different spits.

Category C Remainder. The fragment *could* be genetically identical to others based on its mtDNA haplotype and microsatellite profile but there was not enough microsatellite information to confirm this. To fall into this category, eggshell fragments share at least one allele and must have no contradictory alleles. These samples should not be dated but should also not be used to support the single event argument and are therefore not used in any of the subsequent analysis.

Despite incomplete microsatellite data of most pieces, it was possible to definitively assign three fragments to a single egg (Table 2: Eucu2.1). The DNA analysis showed that samples CJ15, CJ21 and CJ39 were genetically identical at both the mtDNA and at four genotyped microsatellite loci (Category B). A 'Probability of Identity' (PI) assessment for these samples was carried out as implemented in GenAlEx (Peakall and Smouse, 2006). The PI estimates the probability that two unrelated samples, will by chance

Table 2
All eggshell fragments individualised by species, haplotype and microsatellite (Diro = *D. robustus*; Emcr = *E. crassus*; Eucu = *E. curtus*). Haplotypes and microsatellites indicated by digits separated by decimal point. Numbers in columns are sample nos. Samples 15, 21 and 39 (outlined) are genetically identical. Underlined samples were submitted for radiocarbon dating (see Table 2).

Provenance	Eggshell sample ID by species, haplotype and microsatellite								
	DiRo 1	DiRo 2	EmCr 1	EmCr 2	EmCr 3	EuCu 1	EuCu 2	EuCu 2.1	EuCu 3
4-J-2-i-NE			18				80	39	
4-J-2-i-SW	14		57		35				
4-J-2-i-SE		27							
4-J-2-ii-NE							51	15	34
4-J-2-ii-NE			13						
4-J-2-ii-SW	58								
4-J-2-ii-SW	24								
4-J-2-ii								31	
4-J-2-iii-NW						32,49	50		
4-J-2-iii-NE									40,41, 46
4-J-2-iii-SW						56			30
4-J-2-iii-SE									22, 28
4-J-2-iii-SE									52
4-J-2-iv-			26						
4-J-2-iv-NE			33				47		
4-J-2-iv-SW			60,61		23				
4-J-2-iv-SE								21	
4-J-2-v-NW			42						
4-J-2-v-SW			20						
4-J-2-v				38					
4-J-2-v				54					

have the same multilocus genotype. To calculate the PI we used the microsatellite allele frequencies for *E. curtus* in North Canterbury as a reference (Allentoft et al. in press), as these are likely to represent the true level of genetic diversity in a population of this species. For the three *E. curtus* samples in question, two showed identical alleles in all five microsatellite markers and two showed identical alleles in four of the five markers. The chance of this happening for unrelated samples was calculated to PI = 1.5E-5 and 0.001 respectively, confirming that these pieces were very likely from the same egg. The fact that these fragments were from spits i, ii and iv of the oven shows that the oven fill accumulated rapidly and provides additional support for the single event hypothesis.

4.2. AMS dating

At least one Category A fragment from each of the five spits was dated ($n = 9$).

The AMS conventional radiocarbon age (CRA) results all lie within the range of 618–687 yr b.p. Calibrated using the Southern Hemisphere curve, SHCal04 (McCormac et al., 2004), there is no suggestion of time depth: the AMS date series (Table 3; Fig. 2) is statistically an isochron. Calibrated ages for this time period derived from the SHCal13 (Hogg et al., 2013) curve do not differ by more than a year from those derived from the SHCal04 curve.

Table 3
Moa eggshell AMS age determinations calibrated with DateLab v3.5 (Jones and Nicholls, 2002) using the Southern Hemisphere terrestrial calibration curve SHCal04 (McCormac et al., 2004).

Sample#	Taxon	Provenance	Lab no.	CRA (yr BP)	Calibrated range CE	δ13C (‰)
CJ20	*E. crassus*	4-J-2-v-SW	NZA34420	676 ± 25	68% 1302 (0.259) 1324 1342 (0.25) 1363 1376 (0.157) 1389 95% 1298 (0.945) 1391	−12.3
CJ22	*E. curtus*	4-J-2-iii-SE	NZA34421	687 ± 25	68% 1299 (0.26) 1319 1350 (0.228) 1368 1371 (0.175) 1385 95% 1291 (0.38) 1329 1334 (0.572) 1390	−15.3
CJ23	*E. crassus*	4-J-2-iv-SW	NZA34416	646 ± 30	68% 1317 (0.508) 1353 1383 (0.184) 1397 95% 1301 (0.664) 1365 1375 (0.278) 1405	−14.9
CJ39	*E. curtus*	4-J-2-i-NE	NZA34412	641 ± 25	68% 1320 (0.5) 1349 1386 (0.167) 1396 95% 1305 (0.659) 1361 1377 (0.293) 1405	−17.6
CJ42	*E. crassus*	4-J-2-v-NW	NZA34417	649 ± 25	68% 1318 (0.533) 1352 1384 (0.15) 1394 95% 1302 (0.691) 1363 1376 (0.259) 1402	−12.5
CJ49	*E. curtus*	4-J-2-iii-NW	NZA38894	637 ± 25	68% 1321 (0.466) 1347 1386 (0.191) 1397 95% 1309 (0.632) 1360 1378 (0.316) 1407	−16.5
CJ57	*E. crassus*	4-J-2-i-SW	NZA34414	618 ± 25	68% 1324 (0.309) 1342 1389 (0.357) 1405 95% 1317 (0.458) 1353 1382 (0.492) 1417	−14
CJ58	*D. robustus*	4-J-2-ii-SW	NZA34418	669 ± 25	68% 1308 (0.234) 1328 1335 (0.296) 1360 1378 (0.149) 1390 95% 1299 (0.723) 1369 1370 (0.225) 1393	−12.2
CJ60	*E. crassus*	4-J-2-iv-SW	NZA34419	654 ± 25	68% 1317 (0.53) 1353 1383 (0.143) 1393 95% 1300 (0.71) 1366 1374 (0.247) 1400	−14.3

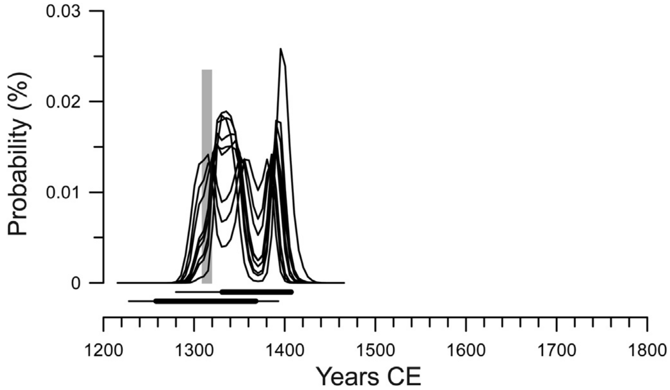

Fig. 2. Calibrated likelihood distributions of calendar ages of nine radiocarbon dates on moa eggshell pieces from Oven Pit 1. Horizontal bars are plots of the 68% (thick lines) and 95% (thin lines) confidence ranges for each of the two calibration peaks for all moa eggshell dates in Higham et al., 1999. All dates calibrated using Datelab® V 3.5 (Jones and Nicholls, 2002) and the Southern Hemisphere terrestrial calibration curve SHCal04 (McCormac et al., 2004).

Although the almost complete overlap of all the likelihood ranges shows that the corpus of dates represents an isochron, the major fourteenth-century fluctuation in the radiocarbon calibration curve results in a bimodal plot with a span of ≈140 years. The greater areas under the earlier peaks of the calibration probability curves suggest that the event was more likely to have occurred in the first half of the 14th century than later.

5. Bayesian analysis

The results of the Bayesian recalibration are shown in Fig. 3. We generated HPDs (Highest Posterior Densities) for the start and end of the sequence (Fig. 3). The 68% HPD for the start was very sharp and had its maximum probability at about 1320. Similarly the peak of the 68% HPD for the end of the sequence was very sharp and firmly in the first half of the 14th century. We also generated an HPD for the duration of the sequence (Fig. 3 inset) which indicates (95% confidence) that the duration was no more than 25 years. Therefore the sequence represents, at most, a period of no greater than thirty years and is entirely consistent, given the nature of the calibration curve in the 14th century CE, with the oven having been filled with midden in a single event that occurred some time after the early 1320 s and no later than about 1350.

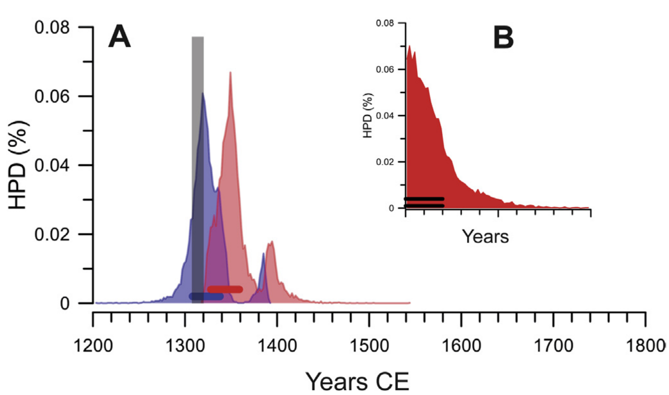

Fig. 3. Bayesian analysis of calibrated radiocarbon dates. Main: 68% HPDs for the start (blue) and end (pink) of a ‘single-phase’ event represented by the nine radiocarbon ages on moa eggshell fragments from Oven Pit 1; grey rectangle represents the 68% confidence interval for the age of the Kaharoa eruption, and the probability distribution for the end of the phase extends to mid- to early- 1320 s CE. Inset: HPD for the span of the event represented by the 9 radiocarbon ages; upper line, 68% confidence interval, lower line, 95% confidence interval. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

6. Discussion

The application of new aDNA techniques to archaeological dating methods has allowed us, for the first time, to obtain multiple independent radiocarbon dates on an “ideal” dating substrate from a single, rapidly accumulated deposit. The contemporaneity of materials in the deposit meant that Bayesian methods could be employed to develop a high-precision chronology for the deposition event. The results placed that event in the first half of the 14th century CE. This is some 50 years later than a postulated settlement date for New Zealand of c. 1280 CE or earlier (Wilmshurst et al., 2008). In fact the 1280 (or earlier) date for the settlement of New Zealand requires some consideration. It was based on the combined probabilities of a number of AMS dates on moa eggshell from Wairau Bar (Higham et al., 1999). Since then palaeoecological data have been found to be not inconsistent with this date (Newnham et al., 1998, Wilmshurst and Higham, 2004, 2013) and subsequently 1280 has been used as the *terminus post quem* (TPQ) for New Zealand settlement as a whole (Wilmshurst et al., 2008, 2013). In fact, the basis for the original 1280 date is a corpus of moa eggshell dates from the Wairau Bar burials (Higham et al., 1999) with a similar probability span to our series; the difference being largely a matter of interpretation. All of the dates (including those on seeds cited as palaeoenvironmental evidence for human presence cited in Wilmshurst and Higham (2004)) have their highest probabilities in the 14th century, with tails that stretch into the late 13th century. Yet these have been cited as evidence for a late 13th century occupation, as if the calibration curves represent temporal spans rather than probability distributions.

Tephrochronological evidence, specifically the Kaharoa tephra, can also be brought to bear on the question of dating New Zealand settlement (Lowe et al., 2000, 2004). The Kaharoa eruption was dated using a “wiggle matching” method that took advantage of the otherwise inconvenient shape of the calibration curve (McFadgen et al., 1994). The result was a very precise age range for the eruption of 1314 ± 6 CE (Hogg et al., 2002). No intact cultural horizon has ever been found sealed beneath a primary air fall deposit of Kaharoa tephra so the date of the event provides a possible TPQ for the colonization of New Zealand. Recently cited evidence of a cultural horizon overlaid by Kaharoa tephra (Furey et al. 2008) is unconvincing. The soil described is not a definite example of primary air fall tephra; if it is Kaharoa ash, which is not demonstrated, it is likely redeposited from upslope. If Oven Pit 1 truly represents a single event, then the posterior probability age distribution of 1320–1350 CE, combined with the high precision age for the Kaharoa Tephra (Hogg et al., 2002), can define a benchmark for the chronology of the site, and for the colonization phase in New Zealand. The previous benchmark was the eggshell dates reported by Higham, Anderson and Jacomb in 1999, which were calibrated using the earlier, IntCal98, Northern Hemisphere, curve (refer McFadgen, 2007) with a southern hemisphere correction (McCormac et al., 1998). Recalibrated using SHCal04 (or SHCAL13, which generates identical calendar ages for this period) and treated in the same way as the newly excavated oven eggshell, the individual dates in the two series have very similar distributions, providing strong support for the contention (Higham et al., 1999) that the site was occupied only briefly. The revised calibrated age ranges (Fig. 2) for the dates presented in Higham et al. (1999) include the period immediately after the Kaharoa event, which is consistent with the chronology presented here.

Palaeoenvironmental data have been used to support arguments for a pre-Kaharoa settlement date – estimated to be

consistent with the often-cited 1280 CE date (Newnham et al. 1998, Wilmshurst et al., 2013). However, non-archaeological data must be treated with caution when drawing archaeological inferences; such data have been misinterpreted in the past (e.g. Sutton 1987, 1994; reassessed by Anderson, 1991; Higham et al., 1999) and should be treated only as plausible indicators of pre-Kaharoa settlement until backed up by direct archaeological data.

The TPQ status of the Kaharoa eruption is supported by our analysis wherein the span of the Bayesian derived probability sequence commenced immediately after the Kaharoa event. Although individual radiocarbon dates on short lived material from other parts of New Zealand may suggest an earlier occupation, no other colonization phase site is as well dated as Wairau Bar. At this point, any claim of human settlement substantially earlier than the Kaharoa eruption would require a substantial suite of radiocarbon dates on well provenanced, short-lived samples taken from an intact cultural horizon. A brief period of pre-settlement activity that represents discovery of New Zealand by Polynesians and a reconnaissance of the main islands is allowed in this model but the colonisation process itself did not begin until about the time of the Kaharoa eruption. Once it did begin, Wairau Bar rapidly emerged as a central place for the colonization process.

The results of this study have global implications for the study of human migration and colonization. New Zealand was the last major land mass to be colonized by pre-industrial humans. Uniquely, many of the sites of the colonization phase are still there to be investigated. In stark contrast to other theatres of prehistoric human colonization, New Zealand has an abundant archaeological record dating from the earliest period of settlement, and exceptionally well-preserved evidence of the fauna that the colonists depended on. Wairau Bar is the best candidate globally for a primary colonization site of a major land mass.

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